Computer Modeling Laboratory 5

Written report due: Oct. 4

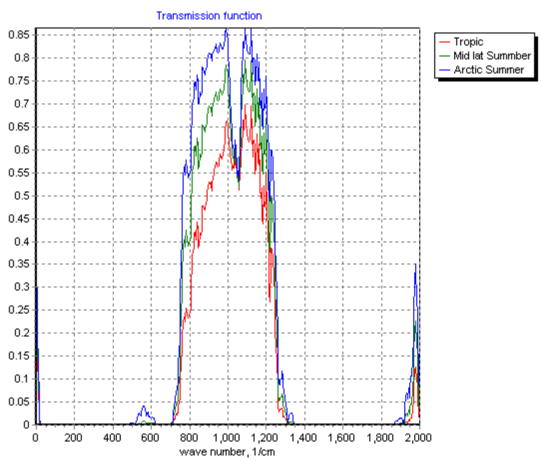
Atmospheric IR spectra and line-by-line radiative-transfer

In this Lab, we will be running a LBLRTM code and interpreting the model results. The LBLRTM was developed in the ATMOSPHERIC AND ENVIRONMENTAL RESEARCH INC.

To browse the FORTRAN source code of LBLRTM click on VIEW LBLRTM

TASK 1
Instruction: to run LBLRTM code for task 1 click on RUN LBLRTM

A. Run LBLRTM using "7 Molecules" option to calculate and plot the transmission function from 0 km to 13 km for the Tropics, Arctic Summer, and Mid-latitude Summer Atmospheres from 0 to 2000 cm^{-1} with a spectral averaging of 10 cm^{-1}.



A.1) Briefly explain major differences between transmission functions calculated for these standard atmospheres.

Transmission function is the highest for the arctic summer atmosphere, followed by transmission for the middle latitude summer, and the lowest transmission is found for the tropical atmosphere. The difference is due to the change of the absorber amount in the atmosphere with latitude as well as due to the line-broadening effect that depends on temperature change with latitude.

A.2) Identify on your plots the main IR absorbing band of O3. Estimate and compare the minimum values of the transmission in this O3 band for these standard atmospheres. Explain your results

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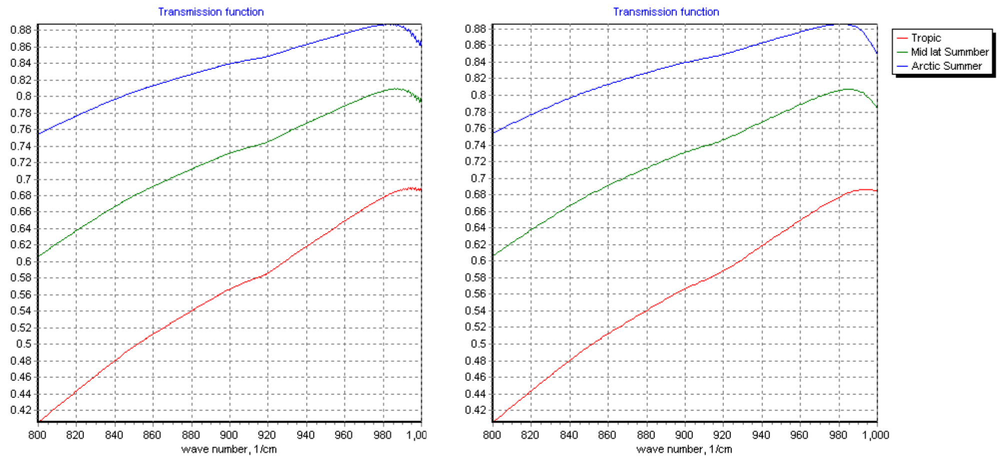
The difference between transmissions is due to the abundance of water vapor and ozone in the troposphere (0-13 km) and molecular absorption in the 0-2000 cm^{-1} wave-number region. The lower transmission in the tropics is determined by higher water vapor content than it is present in the middle latitude atmosphere, whereas the arctic atmosphere is very dry (small absorber amount). Moreover, the change in temperature with latitude affects the half-width of the water vapor absorption. The warmer temperature in tropics results in a larger absorption coefficient as compared to the absorption coefficient for the arctic atmosphere. Thus, the effect of larger concentration and larger absorption results in lower transmission observed in tropics rather than in arctic.

There are several IR absorbing bands of ozone in the 0-2000 cm^{-1} region. Most important feature is found at 1043 and 1110 cm^{-1} (v1 and v3 fundamental vibration modes), where the two bands overlap and are not easily identified on the plot with 10 cm^{-1} spectral averaging. The transmission in this region is practically the same for three cases. One of the reasons is the temperature dependence in the Lorentz line broadening. Change in temperature with latitude affects the half-width of the ozone absorption (similar to water vapor case). At the same time there is a relatively larger ozone amount in the arctic troposphere than it is in the tropical troposphere. The two effects cancel out. Since the water vapor still contributes to the transmission, the lowest transmission in ozone absorption band is found for the tropical atmosphere.

B. Run LBLRTM using "H2O continuum and O3 only" option to calculate and plot the transmission functions with the spectral averaging 1 cm^{-1} and 10 cm^{-1} from 800 to 1000 cm^{-1} for the Tropics, Arctic Summer, and Midlatitude Summer Atmospheres. How does the selection of the spectral resolution affect your plots? Explain why?



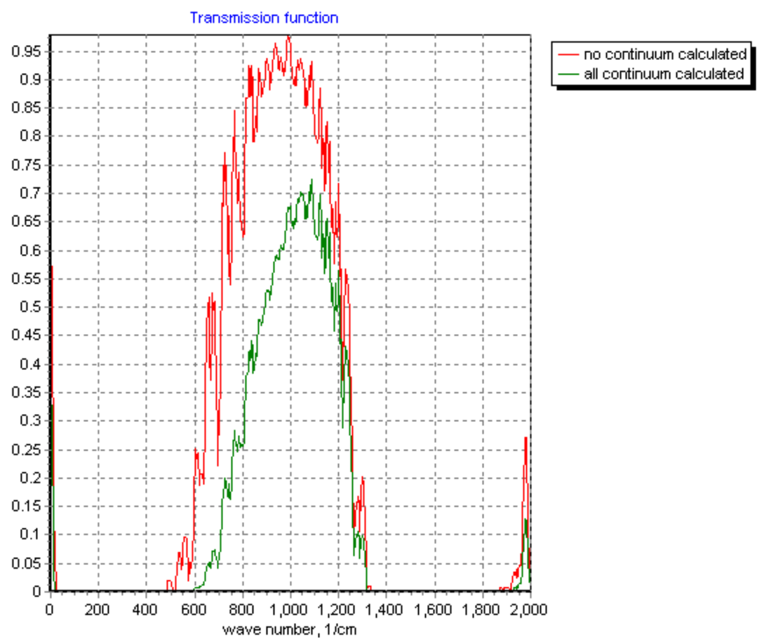
Comparisons of the Transmission function with spectral averaging at 1 and 10 cm-1.

There is no difference in two plots because H2O continuum is a smooth function. The only small difference in two plots is observed only at wave numbers greater than 980 cm^{-1}. At high spectral resolution (1 cm^{-1}) we start to observe contribution from 1043 cm^{-1} ozone band lines.

TASK 2

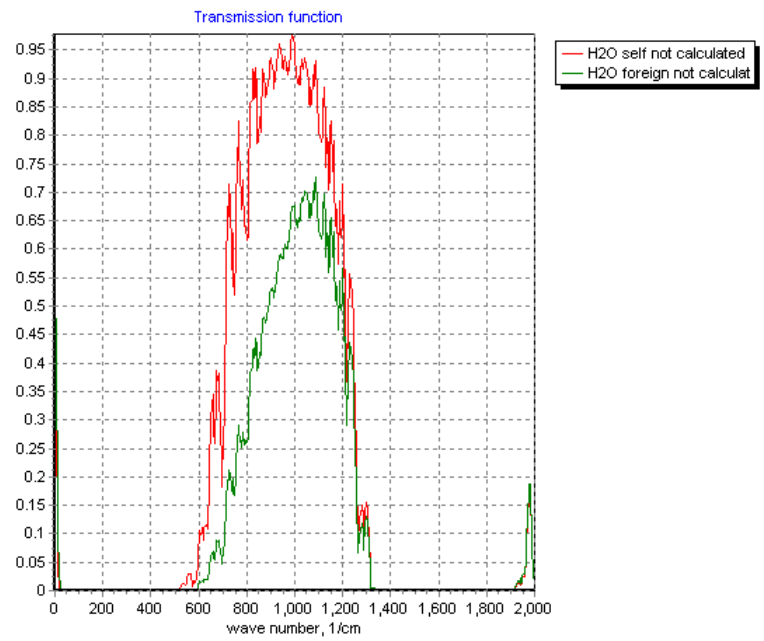
Instruction: to run LBLRTM with various water vapor continuum options, click on [RUN LBLRTM H20]

1) For the Tropical Atmosphere, calculate and plot the transmission spectrum with the continuum absorption turned on and with the continuum turned off. Compare the transmission in the clearest parts of the window. How would this difference change in a dry atmosphere?



The absorption by the H2O continuum significantly reduces the transmission. In the dry atmosphere there is no water absorption. In the presence of other absorbers (ozone, CO2, CH4 etc.) transmission is increased. In the absence if other absorbers the transmission is 1.

2) Calculate the transmission of the Tropical Atmosphere without self-broadening continuum and without foreign-broadening continuum. What is the relative importance of the self-broadening and foreign-broadening continuum in the 8-12 um region?

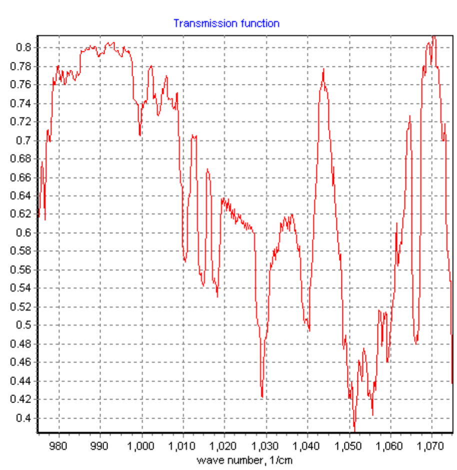


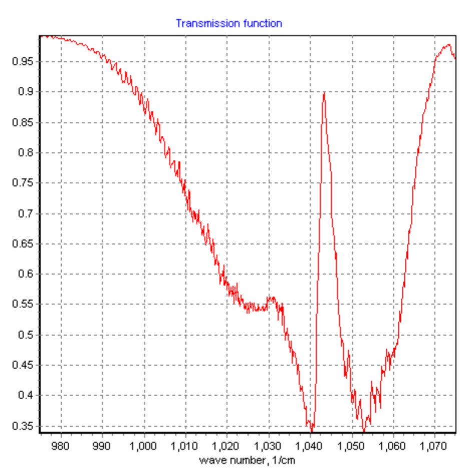
The continuum absorption of a molecule due to the foreign-broadening (collision of H2O with other molecules) and self-broadening (the same molecules) is not equal. The self-broadening plays more important role in troposphere, where the same type molecules are in abundance. The foreign broadening happens higher in atmosphere, where there are fewer molecules. The ratio of self- and foreign- broadening absorption coefficients is 0.002.

TASK 3

Instruction: to run a LBLRTM code with the various spectral resolution in the interval from 975 to 1075 cm^{-1} for different atmospheric layers, click on [RUN LBLRTM]

1) For the spectral resolution of 1 cm^{-1}, calculate and compare transmission of the 0-13 km atmospheric layer and 13-50 km atmospheric layer. Explain the differences.





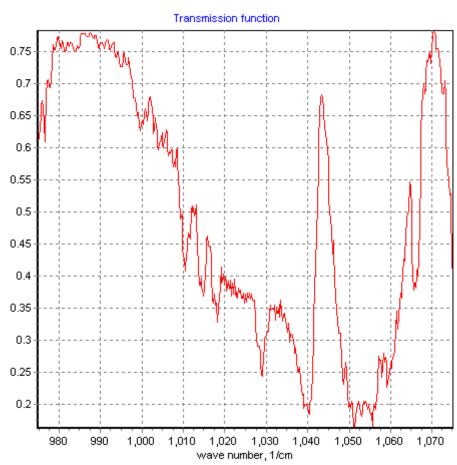
Comparisons of the Transmission function for 0-13 km and 13-50 km at 1 cm-1 resolution.

For a fixed temperature the absorption line strengths do not change, and thus, the absorption coefficient is fixed. Moreover, for a fixed absorber amount the mean optical depth is constant. However, when the pressure decrease (with altitude), the width of the absorption line is decreasing, and thus the absorption is weakening with altitude. Another important parameter is the change of the absorber amount with altitude.

For example, in the tropospheric layer (0-13 km) the water vapor absorption is large (strong pressure-broadening and wider lines) and its density is high, and thus, the transmission through water vapor is weak (small). The main absorbing features in the transmission plot for 0-13 km are due to absorption by water vapor. As for ozone, it's density is not as high in the troposphere as in the stratosphere, and far less than for water vapor. However, ozone absorption lines at 1043 and 1053 cm-1 are still clearly identifiable. Strong pressure broadening of ozone absorption lines allows for strong reduction in the tropospheric transmission.

In the stratosphere (13-50 km layer) the main absorbing feature in the transmission plot is due to ozone. The pressure broadening is weak, thus lines are narrow, and absorption coefficient is small. However, there is a large density of ozone in the stratosphere. Thus, the transmission is reduced.

2) Based on 1), predict how the transmission of the 0-50 km atmospheric layer should look like (i.e., similar to 0-13 km or 13-50 km). Run LBLRTM to check it out. Was your guess right? Why or why not?

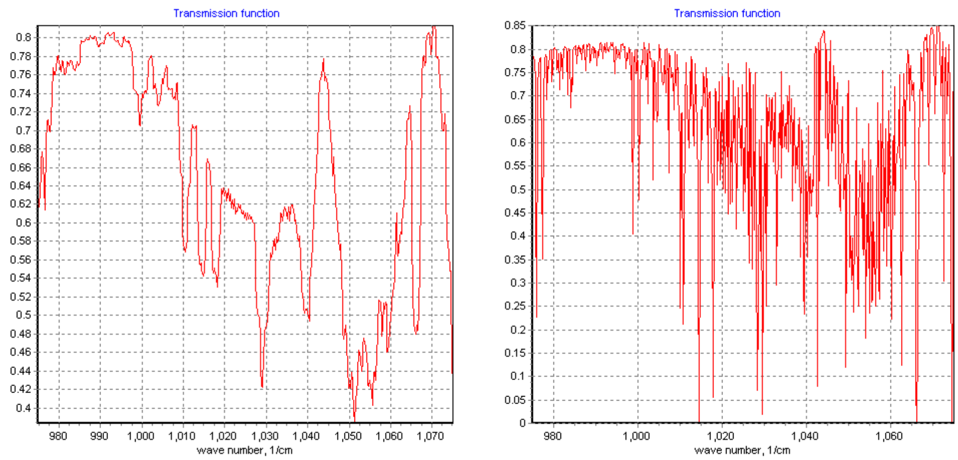


The 0-50 km combined transmission at each wave-number is a superposition of two transmissions at this wave-number:

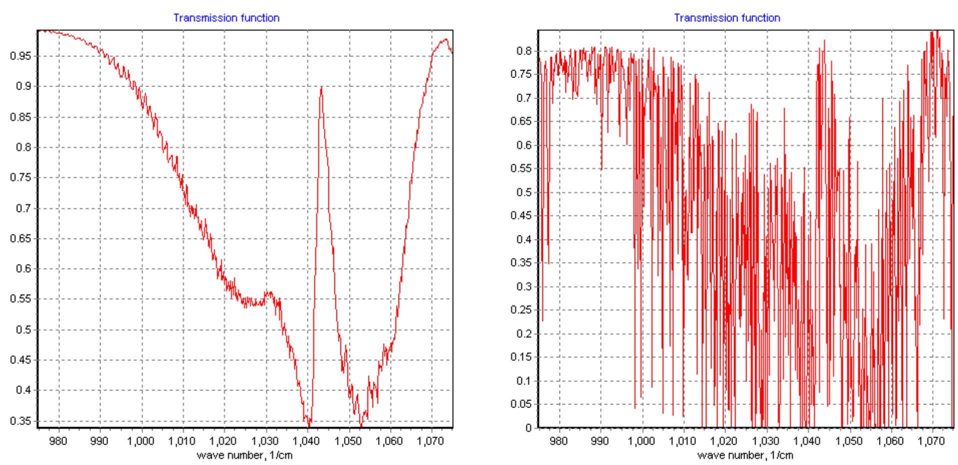
$T_\nu(0\text{-}50)= \exp[-\tau_\nu(0\text{-}50)]=\exp[-(\tau_\nu(0\text{-}13)+\tau_\nu(13\text{-}50))]=$
$\exp[-\tau_\nu(0\text{-}13)]*\exp[-\tau_\nu(13\text{-}50)]=T_\nu(0\text{-}13)*T_\nu(13\text{-}50)$

A combination of optical depths from two atmospheric layers decreases transmission: especially clearly seen effect for ozone absorbing lines. For example, transmission at 1040 cm-1 is 0.17, which is a product of 0.35 (13-50 km) and 0.5 (0-13 km).

3) By increasing the spectral resolution, will you expect to see more fine spectral features in 0-13 km transmission or in 13-50 km transmission? Explain why and then run LBLRTM to verify your predictions.



Comparisons of the Transmission function for 0-13 km at 1 and 0.001 cm-1 resolution.
The increase in spectral resolution in troposphere allows identifying few strong water vapor lines (at 1014 and 1063 cm-1 line's core is saturated, zero transmission) that are averaged when smaller resolution is applied. However, most of the lines are resolved at lower resolution because strong pressure broadening creates wider lines at high pressures.



Comparisons of the Transmission function for 13-50 km at 1 and 0.001 cm-1 resolution.

The higher resolution (small wave-number steps) in the stratospheric transmission offers the discovery of more many more lines. The main reason for not seeing individual line at small resolution is because the lines are narrow. The line width reduces with pressure, and at high altitude (lower pressure) the pressure-broadening effect is small. The Doppler effect starts to play more important role with altitude. The line shape is described better by Voight shape with very strong absorption in the center of the line (Doppler effect) and wider wings from Lorentz profile. The high resolution allows us to see that cores for most of the ozone absorption lines are saturated (zero transmission, very strong absorption).